

Pulling (E. R.)

RESPIRATION

AS AFFECTED BY

CONDITIONS OF THE ATMOSPHERE.

BY

EZRA R. PULLING, M. D.,
OF NEW YORK.

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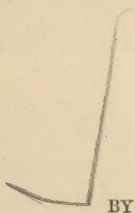
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RESPIRATION AS AFFECTED BY CONDITIONS OF THE ATMOSPHERE.¹

THE various phenomena associated with respiration, whether they are physiological or pathological, can only be satisfactorily studied in connection with the physical agents which sustain or influence that function. The density of the air, its temperature, and the amount of solid, fluid, and gaseous matters which it contains, all have an important bearing on hæmatisation, and on the elimination of the effete products that normally escape by the lungs.

An increase in the density of the atmosphere (the proportions of its constituents remaining unchanged) increases the activity with which its oxygen unites with bases exposed to its action; this being equally true, whether the attendant phenomena be those of combustion or otherwise. The process of oxidation going on in the human body, so far as it is governed by physical causes alone, forms no exception to this rule; we must, then, seek in the vital factors of this process the forces that regulate and control it.

While the vital forces preserve their physiological integrity, a nearly uniform hæmatisation is maintained under wide va-

¹ Read before the New York Medical Journal Association.

riations in the density of the air. The activity of this function is mainly determined by the *wants* of the system, which requires a definite weight of oxygen, depending on muscular exertion, the amount of ingesta, and other circumstances. Theoretically at least, the volume of air inspired under a given physiological condition should bear an inverse ratio to the amount of free oxygen it contains. For the maintenance of the aëriform contents of the vesicles in proper condition, the amount of statical air in the lungs should also bear a direct relation to the rarity of the atmosphere.

There is no doubt that changes in the density or composition of the air are provided for, to some extent, by corresponding alterations in the depth and frequency of respiration; while the long-continued action of any cause affecting its constitution, undoubtedly evokes physiological changes of a permanent character, leading to such a development of the lungs that, by ordinary respiration, a normal hæmatosis may be maintained. The ratio which the capacity and expansibility of the thorax bear to stature and muscular development differs considerably in the aboriginal races, respectively inhabiting depressed basins and lofty plateaux. The dwellers among the higher Alps, whose ancestors, from time immemorial, have occupied regions eight or ten thousand feet above the level of the sea, are known to have an average thoracic capacity much above that of the residents on the plains of Central Europe. In regard to the Indians inhabiting the lofty plateaux of Peru, Mr. Darwin quotes from Alcide d'Orbigny, that, "from continually breathing a highly-rarefied atmosphere, they have acquired chests and lungs of extraordinary dimensions," and that "the cells of the lungs are much larger and more numerous than in Europeans."

In spite of the capacity of self-adjustment exhibited by the respiratory organs, great and rapid changes in atmospheric density disturb more or less all the phenomena of respiration. Since the efficiency of hæmatosis is measured, approximately, by the evolution of carbonic acid, we should expect that the amount evolved would vary in connection with such disturbances. Physiologists, however, are not well agreed in regard to the influence which changes in atmospheric pressure exert

on its production. Lehmann refers to some experiments of Vierordt, which go to show that, under a diminished barometric pressure, an increased amount of this gas is exhaled by the lungs. His experiments have reference only to such atmospheric variations as are due to meteorological changes occurring at a fixed elevation. They are, of course, slight in degree, and their influence on the pulmonary excretions is probably subordinate to other causes, such as humidity and temperature. Lehmann's own experiments, made on small animals confined in an atmosphere artificially rarefied, produced results opposite to the foregoing.

All these experiments are liable to be vitiated by sources of fallacy which cannot well be avoided in connection with the statical carbonic acid in the system, whose amount, varying in accordance with atmospheric pressure, is by no means trivial. Lehmann says that it is present, not only in the blood, but also in the lymph, the parenchymatous juices of many organs, and even in the urine. Its exhalation from a fluid in which it is held in solution occurs whenever atmospheric pressure is reduced; in this way it may be even set free from some of its chemical combinations, as in the case of bicarbonate of soda.

The amount of carbonic acid which can be absorbed by a given fluid or colloid substance is proportioned to the pressure under which absorption takes place. If atmospheric pressure is suddenly increased, its exhalation from the colloids and fluids of the body is temporarily diminished by the amount of the gas taken up through the increased absorptive power of the blood and tissues. Under diminished pressure the phenomena are reversed, exhalation temporarily exceeding production.

In regard to the actual formation of carbonic acid in the body, I think it is now safe to assume that, temporarily, and until respiration becomes adjusted to the change of density in the atmosphere, it is somewhat increased by increased pressure and diminished by diminished pressure. Its production has such a relation to important vital processes, that any cause which tends to increase or to diminish it may have a potent influence for good or for evil. It has a practical bearing on

important questions of hygiene, and must greatly influence us in regard to sending our patients to elevated regions. The subject is full of interest, and needs further investigation by physiologists.

Any reduction in the supply of oxygen necessary for complete hæmatosis, whether that reduction arises from diminished density or a diminished percentage of the gas in the inspired air, awakes the *besoin de respirer*, the hunger for oxygen. In healthy lungs the change, unless excessive, simply tends to increase the frequency or the depth of respiration, or both, without exciting pain, uneasiness, or a sense of constriction or suffocation. In a state of disease, however, all of these symptoms may occur, on account of the reduction in the *complementary* capacity of the lungs and their consequent inability to expand sufficiently to compensate for the change in atmospheric conditions. Patients who have much disorganization of the lung-tissue should ascend to elevated stations by easy stages only. Where the change is great and sudden, not only are the unpleasant symptoms I have mentioned liable to occur, but the expansion of the pulmonary cells may occasion vesicular emphysema, lacerations, hæmoptysis, and other serious accidents.

While there are many cases in which consumption and other diseases affecting the organs of respiration are benefited by the rarefied air of high elevations, we must recollect that these effects are influenced greatly by associated climatic conditions. For example: A locality on the windward slope, and near the summit of a high mountain-range, is usually unfavorable to diseased lungs. The current of air driven against the mountain has its capacity for moisture progressively decreased with its temperature, as it is forced up the slope, till it reaches a point varying in altitude with the amount of humidity, where condensation necessarily takes place. The mist and fog thus produced are peculiarly prejudicial to consumptives.

On the other hand, the leeward side of lofty ranges is usually very dry; the wind, descending from the summits, has already deposited its moisture, and its hygrometric capacity is increasing. Thus, our Great Interior Basin, bounded by two

lofty mountain-ranges on the east and west, and having an altitude of from four to eight thousand feet, offers in most parts a desirable residence for patients requiring a dry atmosphere. Where profuse bronchorrhœa accompanies phthisis, or occurs as an independent affection, the benefits produced by inhaling such an atmosphere are often very striking.

The influence of very great altitudes (over ten thousand feet) on pulmonary phthisis is not well established. The varying and indeed opposite effects described by different observers are perhaps due to modifying causes like those I have mentioned, which have contributed to favorable or unfavorable results. I think that, on the whole, the evidence shows that great elevations are favorable to a large proportion of phthisical patients.

When atmospheric pressure is reduced, that portion of the gases of the blood held by simple absorption must, as we have seen, be diminished, and, if the circulation remain as before, the processes of oxidation are liable to be thereby weakened and retarded. The conditions of a normal hæmatisation can, however, be partially restored by an increase in the rapidity of the circulation, in proportion to the reduction in the capacity of the blood for holding its condensed gases. That such a change in the circulation occurs I think probable. Many years ago I carefully observed the pulses of five persons at the level of the sea, and subsequently at an elevation of about three thousand feet, each series of observations being continued for some weeks. I cannot say that the observed changes were very great, nor was this to be expected from such a comparatively small change of altitude, but they were quite appreciable, consisting in a slight increase in both the force and frequency of the pulse in the more elevated region. This was before the advent of the sphygmograph, and, of course, I had to trust to tactile impressions. It would be desirable, by the aid of this instrument, to obtain tracings of the pulse in a considerable number of persons at different elevations, including the highest habitable regions, for it is a matter of practical importance in its connection with pulmonary affections. Changes in the force and rapidity of the circulation have, I think, considerable influence on incipient tuberculosis. It is a

long-established clinical fact that a reduction in the force and volume of the pulse precedes and attends the early stages of consumption. Some of the benefit resulting from mountain air in incipient phthisis may, therefore, be owing to its dynamic effects on the circulation.

It is not solely through changes in the density of the atmosphere caused by altitude that its effects on respiration are determined; these effects may vary greatly in the same barometric plane. In an atmosphere rarefied by high temperature, and in which a large amount of aqueous vapor takes the place of an equivalent volume of air, the free oxygen may become so reduced as seriously to interfere with the process of respiration. To a person inhaling such an atmosphere, the effect may be like that of breathing "the difficult air of the iced mountain-top." An example will illustrate this point more fully: A cubic foot of dry air under a pressure of 30 inches of mercury, at a temperature of 38° Fahr., weighs 560 grains, and contains 129 grains of oxygen. If this atmosphere be raised to 98° Fahr., and become saturated with moisture, the same volume of it weighs but 489 grains, of which 19 grains are aqueous vapor, leaving but 470 grains of air, containing 108 grains of oxygen; that is to say, dry air at 40° Fahr. contains about one-fifth more oxygen than saturated air at 98°.

The dyspnoea which damp weather causes to patients in whom the expansibility of the lungs is interfered with, is doubtless *partially* due to the reduction in the amount of free oxygen in the inspired air. The great relief from this symptom, sometimes experienced by consumptives who are sent from the damp districts bordering the sea-coast to dry localities in the interior, is, in some degree, owing to the diminished volume of air necessary for respiration in the less humid region, whereby the lungs are partially relieved from the exertion of forced inspiration which the loss of lung-tissue renders necessary.

The physiological relations of *temperature* to the organism are of the highest importance. Thermal changes, acting through the atmosphere, affect readily all unprotected surfaces of the body. Of the entire area to which the air has access, we find that the free surfaces of the pulmonary vesicles form

the larger portion. When we reflect that the whole mass of blood is brought into immediate relation with this extensive pulmonary surface, we might be led to suppose that variations in the temperature of the inspired air would be liable to produce pathological results of a dangerous character. We find, however, in mammals, a structural as well as a functional provision for the protection of the centres of the circulation from vicissitudes that would otherwise prove disastrous.

It may assist us to obtain clearer views of the structure and function of the human lungs, if we consider for a moment some of the relations which exist between the lower sub-kingdoms of animal life and their environment, whether aqueous or aërial.

Among invertebrata each species is usually confined to the whole or part of a zone, often narrow, bounded by isothermal lines, which indicates that the conditions of its existence are mainly determined by temperature. In species that have special organs of respiration, these organs are in an almost rudimentary state, and are incapable of sustaining that function except under nearly unvarying external conditions. The range of the species, therefore, as well as that of the individual, is usually very limited.

Vertebrata have generally a much wider range of existence, due to the greater capacity they possess, through their more complex organization, of adjustment to varieties of thermal conditions, but nothing like complete adaptation to great variations of temperature is found beneath the class of mammals. In this class, and particularly in man, we find respiration taking place under special conditions, which I think have not hitherto received the attention their importance demands. To one of these I wish to call attention, because I think it has a practical significance which should not be overlooked.

According to recent authorities, the volume of air admitted at each ordinary inspiration bears to the residual contents of the vesicles the ratio of one to ten, or at most one to eight. Now, what is the office of this great amount of statical air? It is manifest that the process of respiration would be more effective in aërating the blood if the aërial contents of the lungs were completely changed with each respiratory act, so that

pure air should come in contact with the delicate investing membrane of the air-cells, instead of a compound containing from three to seven per cent. of carbonic acid, which is the usual condition of that in the human lungs.

The residual air in man and in all mammals acts in preserving uniformity of temperature in the air-cells at a point little below the standard of animal heat, and its volume, as compared with that of the tidal air, is nearly in proportion to the normal temperature of the animal.

Since an ordinary inspiration adds only about one-eighth to the statical air previously occupying the human lungs, it can change its thermal condition by only about one-ninth of the difference between its temperature and that of the external air. Thus, if the atmosphere were at 62° Fahr., and the air-cells at 98° , the difference being 36° , the temperature of the gaseous contents of the vesicles would suffer a reduction of only about 4° , as the immediate effect of the act of inspiration. The loss of temperature is actually much less than this, for the air, in passing through the trachea and bronchi, abstracts so much heat from their surfaces that it has acquired nearly the warmth of the body before it reaches the air-cells, or even that point in the smaller bronchial tubes beyond which it passes by diffusion alone. If, as stated by Dalton, ciliary action in the smaller bronchi produces outgoing currents of air along the inner surfaces of the tubes, it appears like a provision for warming the inspired air, at the expense of that which is expired, without directly abstracting heat from any part of the pulmonary tissues. The incoming currents of cold air may thus be supposed to be coated over and heated by a peripheral film of mixed gases and vapor, and in this way brought into a thermal condition approximating that of the vesicles.

In those species of animals whose temperature varies but little from that of the medium in which they live, no precautions against the effect of thermal changes on the organs of respiration are necessary. Reptiles have, in most cases, pulmonary receptacles approaching to the condition of simple sacs: they fill them by deglutition, and after an interval empty them almost completely. The lungs of a frog, according to Prof. Owen, can be so thoroughly emptied of air, while

in situ, as to become reduced to the size of a small pea. In some Chelonians the volume of tidal air nearly equals that of the solids of the entire body.

On the other hand, in birds, whose temperature is higher than that of mammals, a very large proportional amount of space is required for the residual air, which permeates the entire osseous system, while the volume of tidal air is comparatively small.

The fact that extraordinary safeguards against the occurrence of changes of temperature in the air-cells are found in all warm-blooded animals, certainly indicates that such changes are calculated to be extremely injurious to birds and mammals. These safeguards are, however, very effective, and I think we may safely assume that in man, with the exception of some irritant effects on the primary air-passages, the *inhalation* of *dry* air, though very cold, does not ordinarily produce any injurious consequences to the respiratory organs, even of patients laboring under pulmonary diseases.

The very considerable increase in the amount of carbonic acid eliminated from the system by the lungs, under a decided reduction of atmospheric temperature, is a well-known phenomenon whose proximate cause has not, I think, been fully explained. We can readily appreciate the necessity for a provision to compensate by increased oxidation (which implies increased heat) for the cooling of the surfaces of the body from diminished temperature. The *besoin de respirer* appears to be intensified by the impression of cold on the surface of the body, and possibly to some extent by its direct action on the respiratory organs.

The former effect is shown by the gasping and sense of suffocation caused by the sudden immersion of the body in cold water. Under a diminished temperature the respirations are increased both in depth and frequency. Lehmann states that the *percentage* of carbonic acid is also increased. I think this may depend on the fact that inequality of temperature promotes the interdiffusion of gases. This would occur between the tidal and residual air in the lesser bronchial tubes, with a rapidity in some degree proportioned to the difference in their thermal state. I have not seen it stated that the mere

inhalation of cold air, the surface of the body being kept warm, increases the production of carbonic acid to any appreciable extent. Probably an immediate cause of its increased production, when the surface of the body is cooled, consists in the increased quantity of blood sent to the lungs during its recession from the superficial capillaries.

When air which is colder than the body is inhaled, it mingles at once with the residual air, and, as a result of its increase of temperature, its capacity for moisture is correspondingly increased, and it accordingly takes it up from the lungs. The same thing occurs when the air is as warm as or warmer than the body, provided it does not contain vapor enough to become saturated at the vital temperature; but, if saturated at this point, it can take no moisture from the air-cells. Under such circumstances the lungs cease to eliminate the vapor of water.

The exhalation of aqueous vapor by the lungs is doubtless of much importance in the animal economy. Its suppression or serious reduction is attended with great discomfort, and is probably productive of considerable functional disturbance. It seems likely (though exact proof is wanting) that the highly-septic organic matter exhaled from the lungs is intimately associated with the watery vapor, and that the partial suppression of the latter is accompanied by the retention of a portion of the noxious material which should be eliminated with it.

Most physiologists estimate the average volume of each inspiration at about 20 cubic inches, and the frequency of respiration at 18 per minute, which would amount to 300 cubic feet expired in 24 hours. This, if saturated with aqueous vapor at the temperature of the body, would contain 5,700 grains of water.

Valentin, however, states that the mean amount of aqueous vapor exhaled from the lungs in 24 hours is 8,333 grains, which would imply an amount of expired air larger than the foregoing estimate by nearly one-half, or 438 cubic feet in 24 hours. The expired air can remove only the amount of vapor required to saturate it, so that there is an apparent error in some of these estimates, but, I think they may lead to the inference that the exhaled pulmonary gases are saturated with

moisture, or nearly so. Indeed, if we oppose a slip of polished glass or metal to the current of air as it leaves the mouth, a visible film of moisture is deposited on it, even when its temperature is within a few degrees of that of the body. The expired air being saturated when it leaves the lungs, the amount of moisture which these organs eliminate from the blood must bear an inverse ratio to the amount inhaled.

The hygrometric variations in the atmosphere, at our high summer temperatures, must frequently be sufficient to cause very great differences in the exhaled moisture.

There are conditions of the inspired air, even when it is below the animal temperature, in which it may be prevented from carrying off moisture from the body by the lungs. This may happen when it is laden with fog. The small spheres of water, often microscopic, floating into the lungs on the current of inhaled air, are sometimes sufficient to saturate it when vaporized. Fog can undoubtedly become an agent by which the temperature of the statical air in the lungs can be reduced to an injurious extent. Its globules, entering the lungs, abstract from the pulmonary tissues, directly and indirectly, the amount of heat necessary to convert them into vapor. That this amount is by no means trifling, will appear when we reflect that the latent heat of aqueous vapor is such that the evaporation of a few grains of water is sufficient to reduce the entire statical contents of the lungs many degrees.

The inhalation of fog is attended with other injurious consequences, for its minute vesicles, offering such an immense absorbing surface in the aggregate, readily take up from the air the organic and gaseous impurities it contains to the point of saturation. In this way irritating and septic matters reach the air-cells in much larger amounts than would be received from the atmosphere in its usual condition. In the vicinity of New York, fog generally has an acid reaction, and I presume this is its ordinary state in the neighborhood of large cities. This is doubtless one cause of its pernicious effects on diseased lungs.

We must bear in mind that a considerable amount of condensed moisture may be present in the air without being visible, and the injurious effects of atmospheric dampness on the

organs of respiration are oftener due to this invisible suspended moisture than to the vapor held in combination by the air. A fall in temperature of 20° Fahr., say from 70° to 50° , which often occurs during spring and autumn evenings, reduces the hygrometric capacity of the atmosphere by about one-half; so that if its humidity amount to more than one-half of saturation, which it usually does in the neighborhood of the sea, a part of it condenses into minute floating globules, which, unless very numerous, do not affect the transparency of the air. This atmospheric dew, however, is capable of producing quite as decided effects on irritable lungs as visible fog.

While the lungs exhale septic material, they also collect the solid as well as fluid molecules floating in the inspired air. These may be organic or inorganic, soluble or insoluble. A common example of soluble particles, widely disseminated through the atmosphere, consists in the minute crystals of chloride of sodium, arising from the sea-spray thrown up from the agitated surface of the ocean, which, evaporating, leaves the saline particles in a state of extremely minute division, rendering them capable of suspension for an almost unlimited period. The atmosphere of the coast and its immediate neighborhood seems to be more highly charged with these particles than that of the sea remote from land, probably because a larger amount of spray is thrown up along the shore. Spectroscopic indications of chloride of sodium are found far inland, and probably no locality is altogether free from it.

The purest atmosphere holds in suspension an amount of solid material which would soon obstruct the bronchial tubes and air-vesicles were its elimination not provided for. The solid insoluble particles which are inhaled are mostly embedded in the bronchial mucus, and, as the secretions of the air-passages are propelled toward their outlet by ciliary action, these foreign matters are finally ejected with them. When fine dust is, however, inhaled in any considerable quantity, a portion of it reaches the air-vesicles, whence it is not so easily dislodged. When a dust-laden atmosphere is inhaled for a long period, a considerable deposit of its lighter and finer particles undoubtedly takes place in the air-cells.

The entrance of such solid material into the lungs may act as an exciting cause of pulmonary phthisis to a greater extent

than we have hitherto suspected. I think, at least, that we may trace a relation between the admission of dust and the deposit of tubercle in the lungs.

Flint states, in his work on "Physical Diagnosis," that the cells at the apices of the lungs are most permeable to air, and he quotes from Cruveilhier to show that the cells of the superior lobules are the first to expand on inspiration. We should expect that the inhalation of solid matters from the atmosphere, so far as it acts as a cause of tubercular deposit, would first affect those air-cells by which ordinary respiration is chiefly carried on, and which are consequently most liable to receive the floating particles which the air contains. We find that this theory corresponds with observed facts. Tubercular deposit, it is well known, almost invariably commences at the apex of the lung, extending to other regions nearly in the order of their accessibility to air.

Not only is the introduction of foreign material to the air-cells in many cases the initial point in the series of pathological events which constitute the local lesions of phthisis, but I think clinical observation shows that it may also be speedily followed by tubercular deposit even when no previous dyscrasia was evident. It is not difficult to comprehend how this may occur. It is liable to arise from deficient hæmatisation, due to a mechanical obstruction to the diffusion of gases, caused directly by the foreign material, or by the morbid secretions which it elicits from the mucous membrane. The presence of such irritating material on the free surfaces of the delicate tissues investing the air-cells is followed by changes, greater or less in degree, in the capillaries which surround them. The air-cells may, however, partially or wholly cease to perform their functions before the vessels connected with them become obliterated, in which case blood passes through certain pulmonary capillaries without proper aëration, and is returned to the systemic circulation bearing with it the constituents which belong to its venous condition. Such a transmission of effete products into the arteries must produce a dysplasmatic state of the blood, the very condition that promotes tuberculosis.

The loss of permeability in the walls of the air-vesicles is, however, soon followed by closure of the surrounding capilla-

ries, which, I think, must be considered a conservative process, as, by sealing up these vessels, the blood is diverted into other channels where due hæmatisis is maintained.

The presence of a great amount of dust in the atmosphere is likely to outweigh all advantages that a climate otherwise suitable for consumptives may afford. One of the chief advantages of a sea-voyage for phthisical patients consists in the almost complete exemption it affords them from the injurious effects of dust.

The presence of minute organic particles constitutes a serious vitiation of the air, and often leads to important pathological results. All the contagia which are propagated through the atmosphere are probably received into the system in this form. Air which is vitiated by respiration contains organic exuvie in a state of such minute division that the microscope can scarcely educe its specific characters; yet it is highly septic, and, if it be either retained in or reintroduced into the air-cells, is no doubt capable of producing local irritation, and, under some circumstances, toxicæmia from absorption.

We have exhalations of an organic character contributed to the atmosphere by the flora of particular localities; that they are capable of producing marked effects on the air-passages, no one who has suffered from "hay-asthma" will be disposed to deny. Pulmonary affections are, beyond question, often influenced by the peculiar qualities of the atmosphere derived from the vegetation prevailing in various regions. We know that there are portions of many officinal plants which, when floating in the air in a finely-divided state, affect powerfully the respiratory organs, as, for example, ipecacuanha or capsicum.

The effect of vegetation in imparting therapeutical properties to the atmosphere is sometimes very decided; the most noteworthy instance within my knowledge is to be found in the remarkable amelioration of symptoms occurring in phthisical patients who resort to the forests of some of the Southern States, where the *Pinus Australis* is the prevalent growth. Some time ago I published a short account of its remedial effects, in the NEW YORK MEDICAL JOURNAL; I may add that, since that time, I have received further confirmation of its extraordinary efficacy.

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